The Massachusetts Shoreline Change Project: 1800s to 1994

Technical Report

by

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INTRODUCTION

This report provides technical and explanatory material to facilitate the interpretation and use of the shoreline change maps and database of shoreline rates-of-change developed for the Massachusetts Shoreline Change Project. The data set described here consists of historical shoreline positions compiled into a Geographic Information System (GIS) from a variety of map and aerial photograph sources. These shorelines are used to examine temporal changes in the position of the shoreline, generally since the mid-1800s when surveying standards were established for the production of accurate maps of coastal areas. This current effort updates the previous project and now includes a 1994 shoreline generated from National Ocean Service (NOS) aerial photography.

Shoreline position measurements for various time periods can be used to derive quantitative estimates of the rate of shoreline change (erosion or accretion). These rates can be used to further our understanding of the magnitude and timing of shoreline changes in a geologic or scientific context and of the evolution of coastal environments in response to wave and current processes. This knowledge, in turn, provides a basis for the implementation of sound coastal zone management strategies.

The shoreline positions presented here were compiled using several historical map and near-vertical air photographic data sources and different analytical techniques. As such, there are a number of potential sources of error that affect the accuracy of the shoreline positions shown on the shoreline change maps. Analysis of the various sources of error suggests that the individual shoreline positions are generally accurate to within +/- 8.5 meters (28 feet). The rates of shoreline change (the focus of this project) derived statistically from these shorelines, however, have a resolution of +/- 0.12 meters/year (0.4 feet/year).

This report assumes familiarity with coastal processes and is thus intended for those with a background in coastal geology, oceanography, or geography, such as professional engineers and coastal geologists. The rich technical literature on the topic of shoreline change mapping and interpretation is referenced where applicable throughout the document.

Section One of the report discusses the data sources and analytical methods used to compile the historical shoreline database. Section Two discusses shoreline rate-of-change statistics, including methods used to generate the rate-of-change database. Finally, Section Three provides an explanation of how to interpret the shoreline change maps and rates-of-change, using examples of different types of shoreline evolution found along the Massachusetts coast.

SECTION ONE - COMPILATION OF SHORELINE CHANGE MAPS

This section describes the data sources and techniques used to generate the shorelines, as well as the errors associated with each data source.

Data Sources

Previous projects compiled most of the available historical shoreline data for the Massachusetts coast into a GIS compatible format (Benoit, 1989; O'Connell, 1997), covering the mid-1800s to1978, and in limited areas 1982. The present study uses digital orthophotography, generated from National Ocean Service (NOS) aerial photographs that were taken in 1994, to delineate a new shoreline and adds it to the GIS database. The data sources and procedures used to accomplish this are described below.

A total of six different data sources were used to obtain historical shorelines for this study: 1) NOS topographic maps (T-sheets), 2) NOS hydrographic maps (H-sheets), 3) Federal Emergency Management Agency (FEMA) Flood Insurance Study topographic maps, 4) printed orthophotographs, 5) aerial photographs, and 6) digital orthophotographs. The early shorelines (1800s to 1950) were digitized exclusively from NOS T- and H-sheets (see Benoit, 1989 for description of these resources). The 1970s-vintage shoreline (mostly 1978) was compiled by digitizing FEMA topographic maps, printed orthophotographs, and aerial photographs. These early data sets were digitized and placed into a GIS-compatible format using the Metric Mapping System (Clow and Leatherman, 1984; Benoit, 1989). For this study, the 1994 shoreline was digitized directly within ArcView GIS software from geographically-oriented orthophotographs supplied by the Massachusetts Office of Coastal Zone Management (CZM).

Metric Mapping System

As described above, the Metric Mapping System (MMS) (Clow and Leatherman, 1984) was used to generate historical shorelines from all data prior to 1994. The MMS employs separate procedures for deriving shorelines from maps and air photos. A complete description of MMS use in generating the Massachusetts shoreline change database is given in Benoit (1989), in particular Appendix C of that document. Since the publication of Benoit (1989), many of the features found in the MMS have been incorporated as standard features in GIS and digital (softcopy) photogrammetry software. Thus, rather than restate what is found in Benoit (1989), which should be considered the definitive reference for the Massachusetts shoreline data prior to the present study (completed in 2001 using 1994 orthophotographs), the following discussion simply places the MMS in a more modern context.

The analytical procedure for digitizing the shoreline shown on historical maps has been described generally by Leatherman (1983), Anders and Byrnes (1991), and Thieler and Danforth (1994a; 1994b). Known control points (either fixed cultural features or other ground control points shown on the map or the map graticule) are used to transform digitized shoreline coordinates from the coordinate system of the digitizing equipment (typically a large-format, x-y digitizing table connected to a personal computer) to a geographically-referenced map projection. This is a straightforward transformation and is presently a built-in feature of most GIS software such as ArcInfo or MapInfo.

The technique employed within the MMS for deriving shoreline positions from near-vertical aerial photographs is known as space resection (Clow and Leatherman, 1984). Space resection is an analytical technique that uses ground control and aerial camera information to reconstruct the position and attitude of the camera at the instant of photograph exposure. Once the position and attitude parameters are established, a collinear geometric relationship between the camera station, the photograph, and points on the ground can be established that allows geographically corrected shoreline positions to be extracted from the photograph. The major drawbacks to this technique are the following: 1) the large amount of ground control – at least three fully known (x,y) points – needed for each photograph, and 2) the single-frame resection approach results in an independent geographic solution for each photograph. In traditional analytical photogrammetry, these problems are avoided by employing aerotriangulation (American Society of Photogrammetry, 1980). Aerotriangulation reconstructs camera stations for multiple photographs using not only ground control points, but also 'pass points', common features on one or more photos. This approach effectively ties the photos together with respect to their spatial relationships. Largely because of these advantages over single-frame space resection, aerotriangulation forms the basis of most softcopy photogrammetry software used today (Moore, 2000).

Compilation and QA/QC of 1994 Shoreline

The shoreline used in this study to update the Massachusetts historical shoreline change project was digitized from full-color, digital orthophotographs provided by CZM on CD-ROM. The photos have a resolution of 1 meter per pixel. The aerial photography was flown in September/October 1994 by the National Ocean Service (NOS photographic missions 94061, 94062, 94063, and 94064) at a nominal scale of 1:48,000. The photographs were scanned and orthorectified by EarthData International (Gaithersburg, MD) using camera station information supplied to EarthData by NOS in 1996. The CD-ROMs supplied by CZM to USGS/WHOI Sea Grant contained mosaicked orthophotos at 1-meter/pixel resolution, with boundaries corresponding to the existing CZM shoreline change maps, as well as ArcInfo TIF World File (TWF) georeferencing information.

To verify the accuracy of the 1994 orthophotos, control points were selected on-screen at easily recognizable sites, such as building corners and street intersections. Ground control points were selected based on their stability through time and their proximity to the shoreline. Because the points selected were located adjacent to the shoreline, they provide a measure of orthophoto accuracy near the feature of interest. These sites were then located in the field and the Differential Global Positioning System (DGPS) coordinates were recorded. DGPS coordinates were later compared to the orthophoto coordinates. Results show that the orthophotos comply with National Map Accuracy

Standards (NMAS). The methodology, coordinates, and field descriptions are outlined in Appendix III.

The high-water shoreline visible on the orthophotos was digitized by hand using a line-drawing tool in ArcView GIS 3.2. Various zoom levels were used to provide as accurate a delineation of the shoreline as possible. Along the Massachusetts coast, there are several options for delineating a shoreline:

1) the local wet/dry line on the beach, indicated by the tonal change between wet and dry beach material (sand, gravel, cobble);
2) the high-tide wrack line, created when the high tide deposits seaweed and debris on the upper beach;
3) the vegetation change between *Spartina patens* in the upper marsh and *Spartina alterniflora* in the lower marsh;
4) the algal line on rocky outcrops, indicated by the tonal change between wet surfaces that host algae and dry surfaces with no algae; and
5) the interface between vertical seawalls/bulkheads and open water.

Many previous studies (e.g., Dolan et al. 1980; Crowell et al. 1991) have suggested that the wet/dry line is a relatively stable feature with respect to its horizontal – seaward – movement during a falling tide. We conducted numerous field checks on different beach types (primarily gravel and coarse sand), however, and determined that in these settings the wet/dry line was subject to substantial (up to 15 m) horizontal movement during a tidal cycle. Generally, the shoreline was delineated using the high-tide wrack line. Due to the range in geomorphology along the Massachusetts coast, however, the digitized 1994 shoreline was developed using the most appropriate combination of the above techniques. We believe, therefore, that the end result is the most accurate high-water shoreline achievable with this data set that is compatible with the existing historical shoreline database for Massachusetts.

Review of Existing Historical Data Accuracy

The relatively high geographic accuracy and photographic detail of the 1994 orthophotographs (i.e., roads, buildings, shoreline structures, etc. are accurately shown) allowed the identification of errors in the existing (pre-1994 shorelines) shoreline database. Although this data set was represented to comply with NMAS (which is stated in Benoit, 1989, and printed on the original 1:5000 shoreline change maps), there are inevitably errors in any large spatial data set that more accurate data will bring to light.

There will always be gross, and sometimes systematic errors, in a large data set. In the present case, a gross error could include a misidentification of the shoreline (e.g., along a marsh shoreline or a beach on an over-exposed photograph) or a poor photogrammetric solution being used for a photograph. A systematic error would involve an offset in the shoreline such as occurs with mismatched datums (e.g., an entire shoreline might be shifted if an incorrect datum was used to digitize the map).

In order to identify gross errors in the data, the shorelines must meet certain criteria:

1) There must be an immobile point of reference, e.g. bedrock outcrops, groins, and jetties.
2) The reference (1994) shoreline and the tested (historical) shoreline must disagree at the reference object by a minimum distance that is taken as the diameter of an "error ellipse."

The error ellipse (*E*) can be calculated as follows:

$$E = E_{ref} + E_{test}$$

where E_{ref} and E_{test} are the maximum position errors for the reference (1994) and test shorelines, respectively. For this study, we compute the size of the error ellipse as 17 meters, based on compliance with NMAS of both the 1994 and earlier shorelines. Consequently, there is an error ellipse around any given shoreline point (e.g., at a transect location) that is 17 m in diameter. For example, if a jetty shown on the 1978 shoreline is offset by >17 m from the 1994 shoreline position, it is likely in error, but anything less than 17 m is essentially undetectable since it falls within the error ellipse.

The main point is that we can only be "certain" of position errors that exceed an accuracy threshold of 17 meters. If these errors in the data are normally distributed, then only about eight percent of the data (e.g., at a transect location) should have an error of >17 m, and about half the shoreline data should have an error of about 8.5 m.

We found no systematic errors in this data set. Our inspection of the data revealed a number of locations with gross errors, mostly in the 1978 shoreline. For example, some shoreline data did not pass tests of geologic reasonableness (e.g., interpretation of the data required building groins on a rapidly *accreting* shoreline, which is an uncommon practice).

Our review of the pre-1994 shoreline data resulted in the removal of all or very nearly all of the gross errors in the 1978 shoreline that exceed 17 m. We also found and eliminated some areas where the error was <17 m. We did this only where we could satisfy ourselves that there was indeed a real error. Most often this was in locations where the error was ~13-16 m and neighboring data looked acceptable. There are only a few locations where problems with a shoreline other than 1978 were found (e.g., 5 miles of 1850 shoreline west of Gloucester), but most of these apparent errors are < 17 m. Remaining errors in the data set are likely, but it is also likely that the magnitude of the error is within the statistical limits of our ability to identify them given the criteria above.

A complete list of shoreline errors and remedial steps taken to address the errors is found in Appendix II.

SECTION TWO - SHORELINE CHANGE STATISTICS

This section describes the various statistical methods used to calculate shoreline change data, as well as the methodology used to generate the baseline and transect locations. The methodology used to generate the 1994 shoreline is also described.

Contemporary Rate-of-Change Calculation Methods

Various methods of determining shoreline rates-of-change have been described by Dolan and others (1991), which is widely considered the definitive work on the subject. The following discussion borrows heavily from their paper. All methods used for calculating shoreline rates-of-change involve measuring the differences between shoreline positions through time. Rates of shoreline change are expressed in terms of distance of change per year. Negative values indicate erosion (landward movement of the shoreline); positive values indicate accretion (seaward movement of the shoreline). The following methods are discussed below: End Point Rate, Average of Rates, Linear Regression, Jackknife, and Average of Eras Rates.

End Point Rate

The end point rate (epr) is calculated by dividing the distance of shoreline movement by the time elapsed between the earliest and latest measurements (i.e., the oldest and the most recent shoreline). The major advantage of the epr is its ease of computation and minimal requirement for shoreline data (two shorelines). The major disadvantage is that in cases (like Massachusetts) where more than two shorelines are available, the information about shoreline behavior provided by additional shorelines is neglected. Thus, changes in sign or magnitude of the shoreline movement trend, or cyclicity of behavior may be missed.

Average of Rates

The average of rates (aor) method was developed by Foster and Savage (1989). This method involves calculating separate end-point rates for all combinations of shorelines when more than two are available, and can be extended to incorporate the accuracy of the shoreline position data and the magnitude of the rate-of-change by using a minimum time criterion, T_{min}:

$$T_{\min} = \frac{\sqrt{(E_1)^2 + (E_2)^2}}{R_1}$$

where E_1 and E_2 are the measurement errors in the first and second shoreline point, and R_1 is the epr of the longest time span for the transect (Dolan and others, 1991). T_{min} is the minimum amount of time that must elapse between measured shorelines to ensure that the aor calculation produces results that exceed measurement error. The aor method also produces a measure of the standard deviation and variance of the data. If only two points are available, and the T_{min} requirement is met, then the aor is the same as the epr.

If all combinations of end-point rates fail to meet the T_{min} requirement, then the aor is not used.

Advantages of the aor method include a means to filter "bad" data (by the measurement errors), and the ability of aor to reflect changes in trend and data variability. The major disadvantages are the lack of a computational norm for the minimum time span equation (Dolan and others, 1991), and the sensitivity of the results to the values used in the measurement error values.

Linear Regression

A linear regression rate-of-change statistic can be determined by fitting a least squares regression line to all shoreline points for a particular transect. The rate is the slope of the line. The advantages of linear regression include: 1) all the data are used, regardless of changes in trend or accuracy; 2) the method is purely computational (requires no other analysis such as measurement errors used in the aor method); 3) it is based on accepted statistical concepts; and 4) it is easy to employ. As pointed out by Dolan and others (1991), the linear regression method is susceptible to outlier effects, and also tends to underestimate the rate-of-change relative to other statistics, such as epr.

Jackknife

The jackknife method is implemented as an iterative linear regression that calculates a linear regression fit to shoreline data points with all possible combinations of shoreline points, leaving out one point in each iteration. The slopes of the linear regression lines are averaged to yield the jackknife rate. The advantages of the jackknife are similar to linear regression; the jackknife is also less influenced by outliers of data clusters. The main disadvantage of the jackknife is a lack of increased statistical value given the typically small numbers of shoreline data points used to derive a shoreline rate-of-change. Most historical shoreline studies have < 10 shorelines, and the real statistical power of the jackknife is best utilized with an order of magnitude (or more) data points.

Average of Eras Rates

An "average of eras" rate-of-change is calculated simply by adding each rate-of-change for individual time periods (eras) and dividing by the total number of eras. This results in an overall average for all time periods combined. Its advantage is that it allows for calculation of measures of variation within the data, e.g. variance and standard deviation, and was included in the modified Digital Shoreline Analysis System (DSAS) programming provided by CZM. Despite its advantage, the average of era rate methodology is generally not a common statistic used in generating shoreline change rates.

As discussed below, linear regression was selected as the preferred method to display the long-term rate of change statistic for this project.

Previous Statistical Analyses

The previous statistical analysis of shoreline change in Massachusetts was completed by Applied Geographics Inc. (AGI) in 1996 (see Van Dusen, 1996, included as Appendix IV of this report).

As described by Van Dusen (1996), the basic software used by AGI to determine shoreline rates-of-change was a modified version of the DSAS (Danforth and Thieler, 1992). Van Dusen (1996) summarizes these modifications, the most important of which are described below.

The method used by the transecting program to calculate transect casting locations was changed from the baseline-increment approach to a baseline-vertex approach. The original transect program employed relatively long, straight baseline segments and cast sampling transects along these segments at the desired transect interval (e.g., 50 meters). The modified transect program, however, uses vertices along the baseline as a "flag" to cast a transect. This requires a baseline with vertices located at each desired transect casting location, even along long, straight baseline segments. An example of this difference is shown in Figure 1.

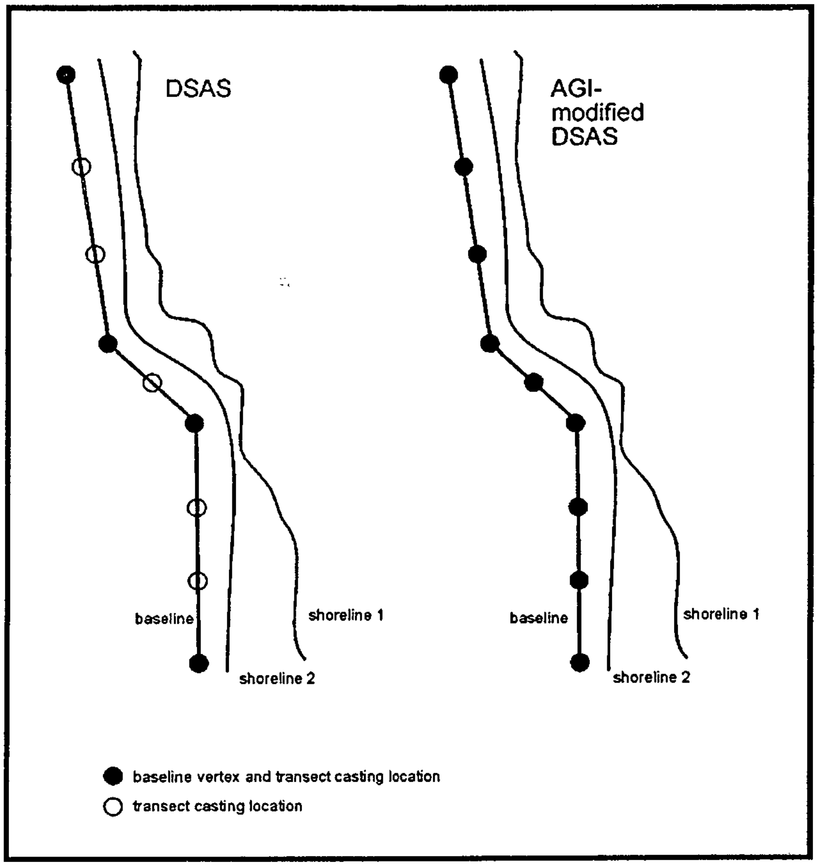


Figure 1. Difference between the transect casting scheme used in the original DSAS and the AGI-modified DSAS. The AGI modification requires a baseline vertex at each transect location.

In order to generate a baseline with vertices at a specified interval, even along straight baseline segments, several ArcInfo commands can be used to modify the baseline as initially drawn so that it contains the requisite spacing between transect casting locations. For example, the UNSPLIT, GRAIN, and SPLINE commands, used in combination, allow the distance between points along a line to be user-specified. A similar approach is described by Van Dusen (1996) using the SPLINE, GENERALIZE, and DENSIFY commands.

Two other changes made to the DSAS involved the following: 1) the rate-calculation program was modified to project the long-term rate of erosion (or accretion) landward (or seaward) 30 and 60 years into the future and draw potential shoreline positions as output files in ArcInfo GENERATE format; and 2) the errors in shoreline position used in the aor rate calculation method (E_1 and E_2 in the equation above) were set to 0 (zero). This resulted in all T_{min} requirements being met for the aor calculation and thus the inclusion of all combinations of end point rates. This is a modification of the original procedure devised by Foster and Savage (1989) resulting in the inclusion of all data. The rationale leading to this modification was that data removed by the original procedure lie within an 'uncertainty range' and are not necessarily errors. Excluding all of the data in the uncertainty range results in some potentially accurate data, and potentially inaccurate data, being removed from the database. This modification had no effect on the long-term rates used by CZM since the long-term statistic used is the linear regression rate, not the aor rate.

Generating the 1994 Shoreline Rate-of-Change Data

Shoreline rate-of-change calculations for this study, using the 1994 shoreline along with the existing historical shoreline data, were made using the AGI-modified version of the DSAS. Once the 1994 shoreline was digitized, field-checked (as described in the previous sections) and edited, the steps described below were employed to generate the rate-of-change statistics.

A measurement baseline was drawn landward of the shorelines. This was accomplished in most cases by using ArcMap to create a buffered shoreline approximately 50 ft (15 m) landward of the landwardmost shoreline, then using the UNSPLIT (to remove excess shoreline points), GRAIN and SPLINE (to set the transect interval) commands to create a baseline from the buffered shoreline. In some cases, the baseline from the previous study by AGI (see Van Dusen, 1996) was used, and occasionally was moved slightly landward from the position established by AGI to accommodate shoreline retreat occurring since the most recent shoreline prior to 1994. In several cases, where the computer generated transects were not perpendicular to all of the historic shorelines, the baselines were drawn by hand following the general trend of the historical shorelines.

The baseline segments were populated with vertices at a 65 ft (20 m) interval, consistent with the previous shoreline change study. As described above, this was achieved using

ArcInfo commands to modify the baseline segments so that the interval was consistent throughout the Massachusetts shoreline.

The transect program is run within a suite of ArcInfo Arc Macro Language (AML) scripts that perform various data formatting actions. These AMLs allow the ArcInfo shoreline and baseline data to be exported to the transect program (which runs under DOS/Windows), and subsequently format the output data from the transect program into an ArcInfo-compatible input format (GENERATE). The transect program output was then converted to a coverage and displayed in ArcInfo to check the completeness and accuracy of the transects generated. Alternate transects, at a 131 ft (40 m) interval, were selected for display on the maps and databases. This procedure was performed iteratively for each of the 91 shoreline change maps produced for the Massachusetts shoreline.

Once the baseline and transects were established, a suite of AML scripts was executed that submit the transect data to the rates program. These AMLs have a similar function to those associated with the transect program, in that various data formatting actions are performed to allow interactive examination of the input and particularly the output data. The output rates data include the following information:

1) transect number;
2) distances between shorelines and rates of change for each time interval (era) between successive shorelines (e.g., 1846-1920, 1920-1950, 1950-1978, 1978-1994); and
3) long-term rate of change calculated by least squares linear regression.

The linear regression statistic was chosen as the preferred long-term rate-of-change statistic. This was done not only to be consistent with the previous analysis by AGI, but also (and more importantly) because scientific opinion seems to be converging on the linear regression method as the best available tool for computing long-term rates of shoreline change (see papers in Crowell and Leatherman, 1999). As described above, the linear regression method of rate calculation has several advantages over other methods. As described below, however, the accurate geologic interpretation of shoreline rates-of-change requires looking at more than just the linear regression rate; rather, it requires examining the geomorphic evolution of the shoreline both on the maps, as well as the rates of change for each era represented by the mapped shorelines.

It is very important to note that due to necessary adjustments in baseline for this project, the location of current transect numbers are not consistent with those reported on the shoreline maps or data tables of the 1997 project. Therefore, shoreline rates of change noted at the end of numbered transects on these shoreline change maps and data tables should **not** be compared directly with previous numbered transects.

<u>SECTION THREE</u> - USING SHORELINE CHANGE MAPS AND INTERPRETING SHORELINE CHANGE DATA

This section provides various examples demonstrating the importance of properly analyzing and interpreting shoreline change data.

Shorelines are constantly moving in response to winds, waves, tides, sediment supply, changes in relative sea level, and human activities. These cyclic and non-cyclic processes change the position of the shoreline over a variety of time scales, from the daily and seasonal interaction of winds and waves, to changes in sea level over thousands of years. Furthermore, shoreline changes are not constant through time and frequently reverse in sign, i.e. accretion to erosion, and vice versa. Most shorelines undergo patterns of erosion and accretion on a daily and seasonal basis, and may be unidirectional or cyclic on a long-term basis.

To measure changes in the position of the shoreline a minimum of several shoreline positions are generally plotted from various historical charts, aerial photographs, ground surveys, and other resources. The distance between each shoreline position is then measured and a "*rate of shoreline change*", the most commonly used statistic to portray the dynamics of shoreline movement, calculated. This rate of shoreline change is based on measuring the movement of the shoreline over a specified length of time. The shoreline "rate of change" statistic should reflect a cumulative summary of the processes that altered the shoreline for the time periods analyzed.

Due to the shifting of shoreline position and human influences on coastal processes and sediment sources, however, it is critical to determine whether the long- or short-term rates of shoreline change reflect present-day shoreline dynamics. This analysis is complicated in areas that exhibit trend reversals (erosion to accretion, and vise versa), or where human activities, such as revetment construction, have affected sediment sources and altered shoreline processes. An understanding and proper application of short-term shoreline changes and long-term data are critical components for effective shoreline management. Specifically, in areas that exhibit significant or frequent shoreline trend reversals, or areas that have been extensively altered by human activities, professional judgment and knowledge of natural and human impacts are essential in determining whether the long- or short-term data should be used for management purposes.

Long-term shoreline change data (e.g. >100 years) can increase confidence in the data in terms of the errors associated with the source material used to generate the data (Crowell and Buckley, 1992; Morton, 1991), and in identifying trend reversals or accelerations and decelerations in the rate of shoreline movement.

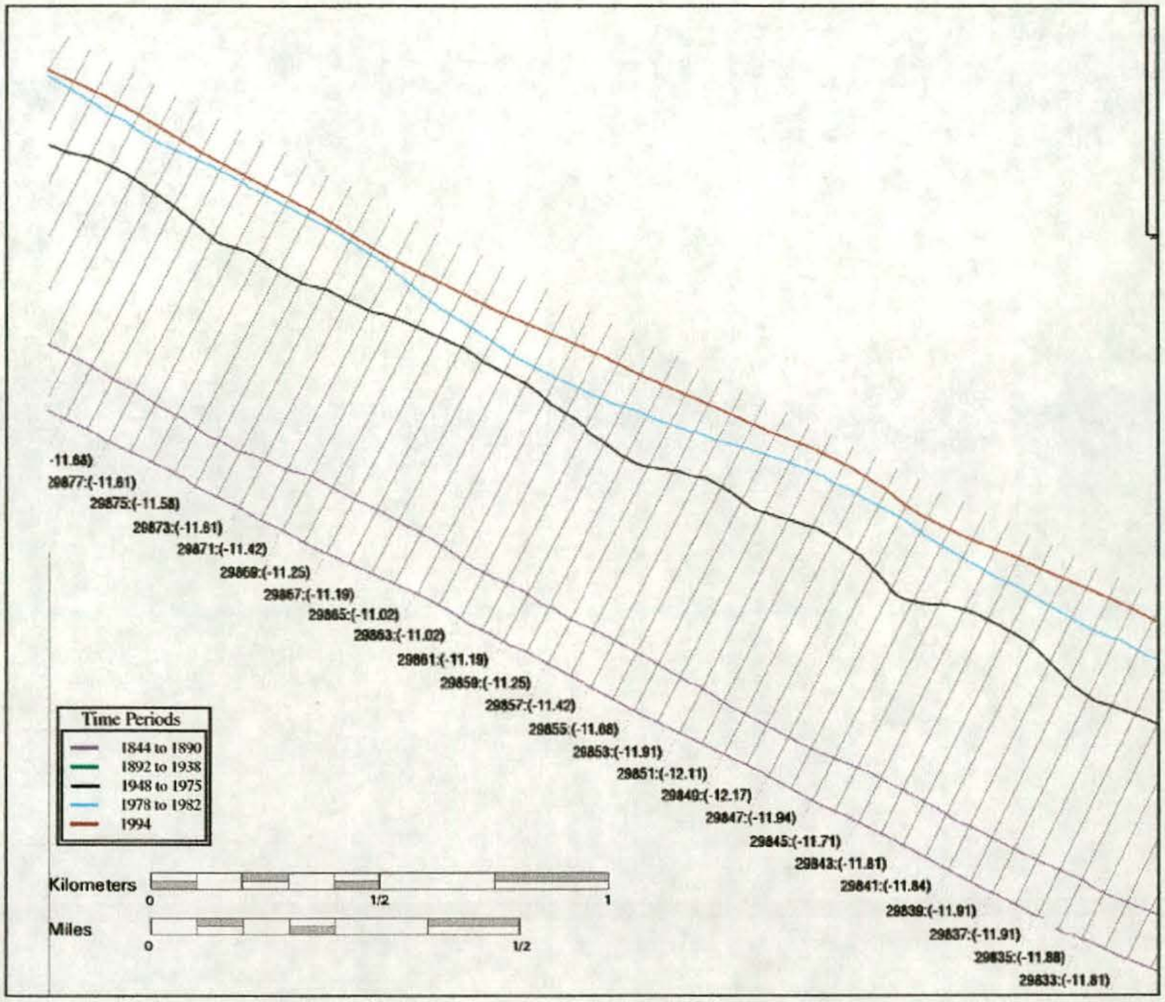
The following examples demonstrate the importance of analyzing short-term shoreline change data for transects in order to determine whether the long- or short-term shoreline change rate is the more appropriate statistic to use in evaluating and managing shoreline dynamics. The following examples are discussed:

- Unidirectional long-term shoreline change trends;
- Shoreline change trend reversals; and
- Human-induced shoreline alterations and influences on data interpretation.

To locate the area of interest for the examples describes below, refer to the Index to Shoreline Change Maps in Appendix I.

Unidirectional Long-Term Shoreline Change Trends

In areas that exhibit *unidirectional* long-term shoreline movement (i.e. long-term continuous erosion or accretion) the calculated long-term "shoreline change rate" reflects the trend of shoreline movement through time and, therefore, can be used with relative confidence for management purposes. For example, Figure 2 depicts a section of the Nantucket south shore (from Shoreline Change Map C89) and the calculated shoreline change data for transect #29859. Based on the dates of the plotted shorelines on Map C89, a unidirectional trend is exhibited, i.e. continuous erosion between 1846 and 1994. A long-term shoreline change rate of –11.25 ft/yr is shown in the data table for Transect #29859, with all plotted shorelines exhibiting a continuous erosion trend. Because this area exhibits a unidirectional linear trend in shoreline movement, the use of the calculated long-term shoreline change rate is appropriate and can be used to extrapolate future shoreline positions.



Transect Number:	First Time Period:		Second Time Period:		Third Time Period:		Fourth Time Period:		Net (overall) Time Period:	Summary Statistics
	Distance*	Rate**	Distance*	Rate**	Distance*	Rate**	Distance*	Rate**	Net Distance Change*	Long Term Annual Shoreline Change Rate**
	1846		1887		1955		1978	1994	1846 to 1994	
29859	-287.53	-7.02	-903.15	-13.29	-221.10	-9.61	-191.37	-11.98	-1603.15	-11.25

Figure 2: Portion of Shoreline Change Map #C89 and Data Table for Transect #29859 Showing Unidirectional Shoreline Change Trend

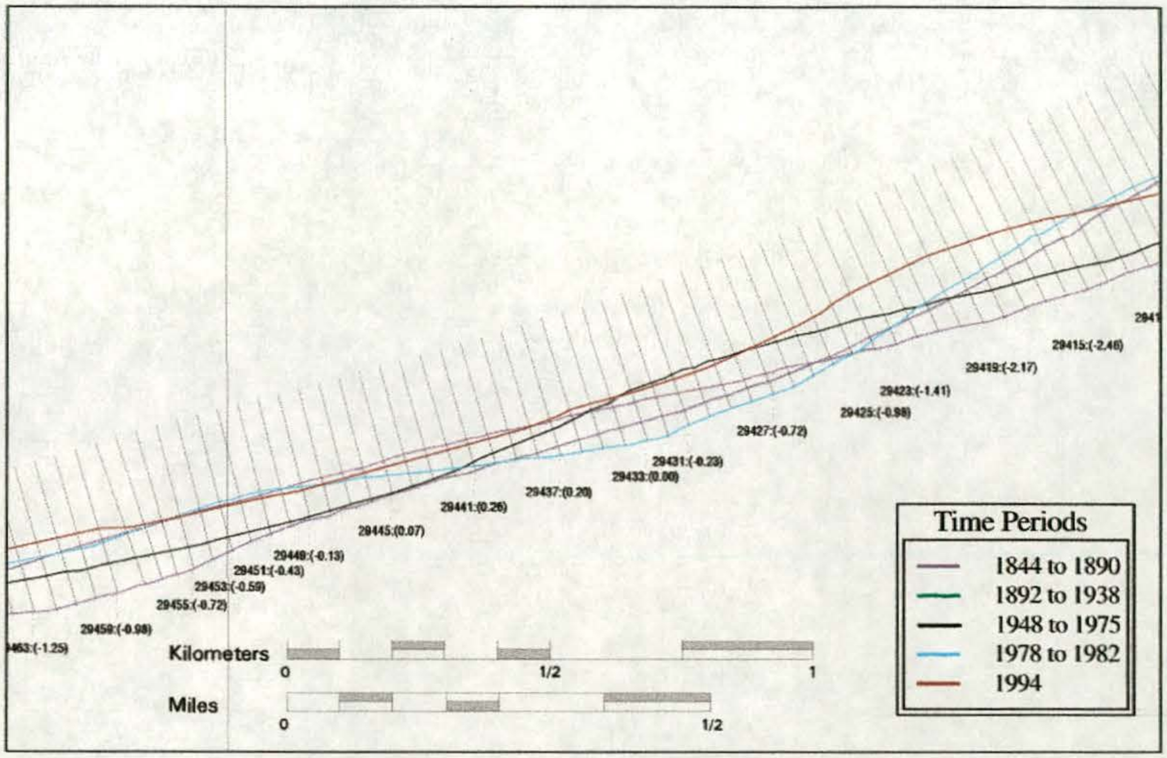
Transect #29859 also demonstrates the difference between using long-term versus short-term rates of shoreline change. For example, although the shoreline change rates for each time period for Transect #29859 depict erosion, each time frame exhibits a different rate of change. Accelerations and decelerations in the rate of shoreline change are common and if only discrete time periods were used, different rates would result.

Therefore, in areas exhibiting a unidirectional trend, all available data (long-term) should be utilized in calculating the shoreline change rate. An exception to this rule is if recent natural and/or human activity has significantly altered coastal processes or sediment supply. When this is the case, sound professional judgment must be used to determine whether the entire database or more recent short-term data are more reflective of current conditions.

Shoreline Change Trend Reversals

Shoreline change trend reversals indicate that a shoreline has undergone both erosion and accretion on a long-term basis. All shorelines undergo both erosion and accretion on a seasonal or yearly basis, however, some areas continue to exhibit trend reversals on a longer term basis. If trend reversals are noted within the database, then the calculated long-term shoreline change rate may not be a useful statistic to manage the shore or predict future shoreline positions. In this case, long-term shoreline movement is non-linear, and outliers (i.e., large magnitude shoreline trend reversals) may significantly bias the long-term rate of change.

For example, Figure 3 depicts a portion of Shoreline Change Map C91 (Nantucket's east southeast shore) and shoreline change data for Transect #29445. Note that the data table shows that Transect #29445 has a long-term annual shoreline change rate of +0.07 ft/yr (calculated from five shoreline positions over a 148 year period between 1846 and 1994), suggesting a relatively stable shoreline. If the long-term rate were utilized for management purposes or setback standards, it would appear that this shoreline is suitable for development or other appropriate uses. However, when individual short-term shoreline position movements used to calculate this long-term rate are analyzed, it is apparent that this area has undergone significant short-term erosion and accretion trend reversals.



Transect Number:	First Time Period:		Second Time Period:		Third Time Period:		Fourth Time Period:		Net (overall) Time Period:	Summary Statistics
	Distance*	Rate**	Distance*	Rate**	Distance*	Rate**	Distance*	Rate**	Net Distance Change*	Long Term Annual Shoreline Change Rate~
	1846		1887		1955		1978	1994	1846 to 1994	
29445	215.03	5.25	-12.40	-.20	-112.50	-4.89	-55.51	-3.48	34.61	.07

Figure 3: Portion of Shoreline Change Map #C91 and Data Table for Transect #29445 Showing Shoreline Change Trend Reversals

The short-term intermediate data for Transect #29445 on Figure 3 reveal that the shoreline exhibits a trend reversal from accretion over the first measured time period between 1846 to 1887 (+215.03 feet), to erosion over the next three time periods between 1887 through 1994 (-12.40 feet, -112.50 feet, and –55.51 feet). Due to the differences in the magnitude of shoreline movements, the larger shoreline movement of 215 feet of accretion between 1846 and 1887 has biased the long-term shoreline change rate towards accretion despite erosion being prevalent for the three subsequent time periods between 1887 through 1994. This example underscores the importance of analyzing all existing short-term data used to generate the long-term rate. The coastal manager or scientist must decide whether the long- or short-term rate (or combination of short-term rates) reflects the actual present-day and/or future conditions and which rate to apply.

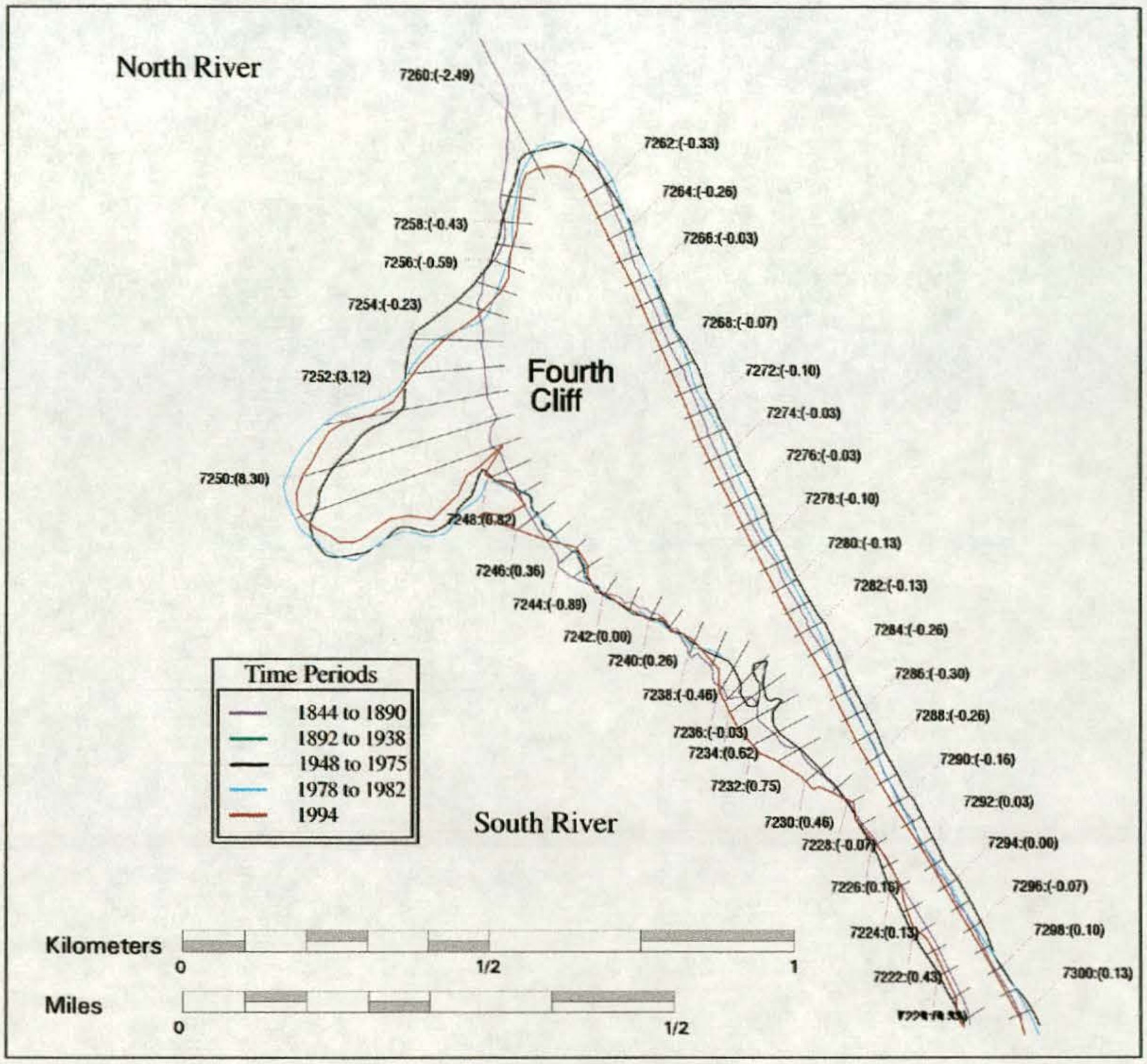
It is interesting to note that these alternating shoreline positions in this area are the result of changing natural coastal processes currently thought to be in response to migrating offshore shoals.

It is suggested that in a case such as this, the three more recently measured time periods exhibiting erosional trends (1887-1955, 1955-1978, and 1978-1994) are a more appropriate measure of present-day conditions and perhaps near-future shoreline positions, although the timing of a trend reversal is impossible to predict.

Human-Induced Shoreline Alterations and Influences on Data Interpretation

Shoreline trend reversals (erosion to accretion or accretion to erosion) can be the result of changes in natural coastal processes (as demonstrated above along the Nantucket east shore) or the result of human interference with coastal processes and sediment supply. The most important causes of human-induced erosion are the interruption of sediment sources (e.g. armoring of coastal banks) and the interference with alongshore sediment transport (e.g. groins). Human interference with shoreline sediment sources and transport patterns can significantly impact the trend of shoreline movement.

For example, Figure 4 shows a segment of Shoreline Change Map #C23 (Scituate) and accompanying shoreline change data for Transect #7294. As noted on the shoreline change data table insert, the long-term shoreline change rate (between 1858 and 1994: 132 years) for Transect #7294 suggests a stable shoreline at 0.0 ft/yr. Significantly, an analysis of the short-term intermediate shoreline change data for Transect #7294 reveal a trend reversal from accretion of +0.59 ft/yr for the earlier time period between 1858-1952 (94 yrs), to erosion of –1.67 and –2.03 ft/yr respectively for the time periods 1952-1978 and 1978-1994 (42 yrs).



Transect Number:	First Time Period:		Second Time Period:		Third Time Period:		Fourth Time Period:		Net (overall) Time Period:	Summary Statistics
	Distance*	Rate**	Distance*	Rate**	Distance*	Rate**	Distance*	Rate**	Net Distance Change*	Long Term Annual Shoreline Change Rate**
7294	1858		1952		1978		1994		1858 to 1994	
	56.10	.59	-43.37	-1.67	-32.38	-2.03			-19.65	0

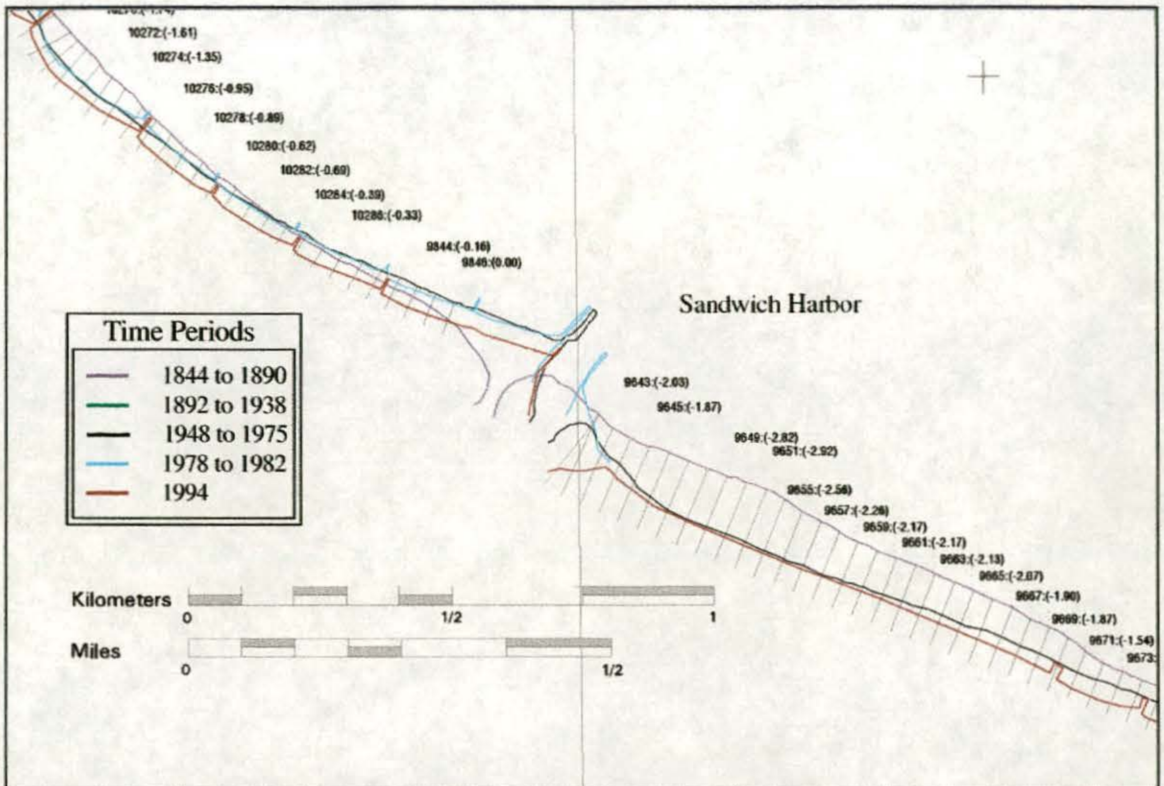
Figure 4: Portion of Shoreline Change Map #C23 and Data Table for Transect #7294 Showing Effects of Human-Induced Shoreline Alterations (revetments) on Shoreline Change

Knowledge of changes in the natural system, as well as significant human interference with the updrift sediment supply for this area, reveal the potential major reasons for this trend reversal.

First and foremost, the major sediment sources for this area have been significantly altered. Four updrift drumlins that historically supplied the major sources of sediment to this area were armored with revetments in the early- to mid- 1900s, thereby significantly reducing source material contribution to this area: thus, the trend reversal to erosion. In addition, the Portland Gale of 1898 created a new inlet immediately updrift of Fourth Cliff (see Map #C23) that appears to be acting as a sediment sink.

These natural and human-induced changes to sediment supply for this area must be considered when selecting the appropriate short- or long-term shoreline change statistic for management purposes. If the updrift revetments that have significantly reduced the sediment sources to this area are well engineered and properly maintained, then the more recent short-term shoreline change data (post-revetment construction) may be the more appropriate statistic that reflects present-day conditions and possible future shoreline positions (O'Connell, 2000). The shoreline change data from 1952 to the most recent plotted shoreline, therefore, should be used for management purposes in a case such as this. In fact, the U.S. Army Corps of Engineers (1994) utilized the short-term erosion rate of –2.2 ft/yr (1952-1978) for this area to calculate the future position of the shoreline, and to determine the number of houses that may be lost to erosion in calculating their benefit/cost ratio in consideration of a beach nourishment project for this area.

Figure 5 provides a second example highlighting the importance of recognizing human interruption of sediment supply and the necessity of analyzing all data used to calculate the long-term shoreline change rate when determining the appropriate rate. Figure 5 shows a section of the Sandwich shoreline (Map #C47) and the accompanying shoreline change data for Transect #9649. As shown by Figure 5, the initial adjustment of the shoreline has significantly biased or influenced the calculated long-term rate as a result of jetty construction at the entrance to Sandwich Harbor.



Transect Number:	First Time Period:		Second Time Period:		Third Time Period:		Fourth Time Period:		Net (overall) Time Period:	Summary Statistics
	Distance*	Rate**	Distance*	Rate**	Distance*	Rate**	Distance*	Rate**	Net Distance Change*	Long Term Annual Shoreline Change Rate**
9649	1860		1952		1994				1860 to 1994	
	-343.73	-3.74	-8.17	-.20					-351.90	-2.82

Figure 5: Portion of Shoreline Change map #C47 and Data Table for Transect #9649 Showing Influence of Jetties on Shoreline Change

As noted on Figure 5 depicting a portion of Map #C47, jetty construction resulted in initial downdrift erosion for approximately 5,600 linear feet, with a maximum landward movement of the shoreline of -361 feet (O'Connell, 1997). Transect #9649 exhibits a long-term (1860-1994; 134 years) shoreline change rate of –2.82 ft/yr. However, as also noted on Figure 5, the shoreline adjustment to the construction of the jetty resulted in measured downdrift erosion of -343 feet between 1860 and 1952; with a short-term shoreline change rate of –3.74 ft/yr. Significantly, following initial adjustment (erosion) of the downdrift shoreline in response to the presence of the jetty, the shoreline between 1952 and 1994 has eroded only 8 feet (-0.20 ft/yr). In a case such as this, if the jetties are properly engineered and maintained, it is more appropriate to use the post-jetty adjusted shoreline movements for management purposes.

Summary

The examples provided above demonstrate some of the necessary cautions in using and interpreting shoreline change data. Using long-term data increases data confidence in terms of potential errors associated with source material used to generate the shorelines, and contributes towards identifying trend reversals for data analysis and interpretation.

However, the above examples underscore the necessity of analyzing all short-term, intermediate shoreline change data used to generate the long-term shoreline change rate. This is particularly relevant when a trend reversal has been identified. Furthermore, knowledge of human activities along the shore, particularly those activities that affect sediment sources (such as revetment construction) or interrupt alongshore sediment transport (such as jetties) must be analyzed in the context of the long-term rates of change. In no circumstance should the long-term shoreline change rate be used exclusively before analyzing these other factors.

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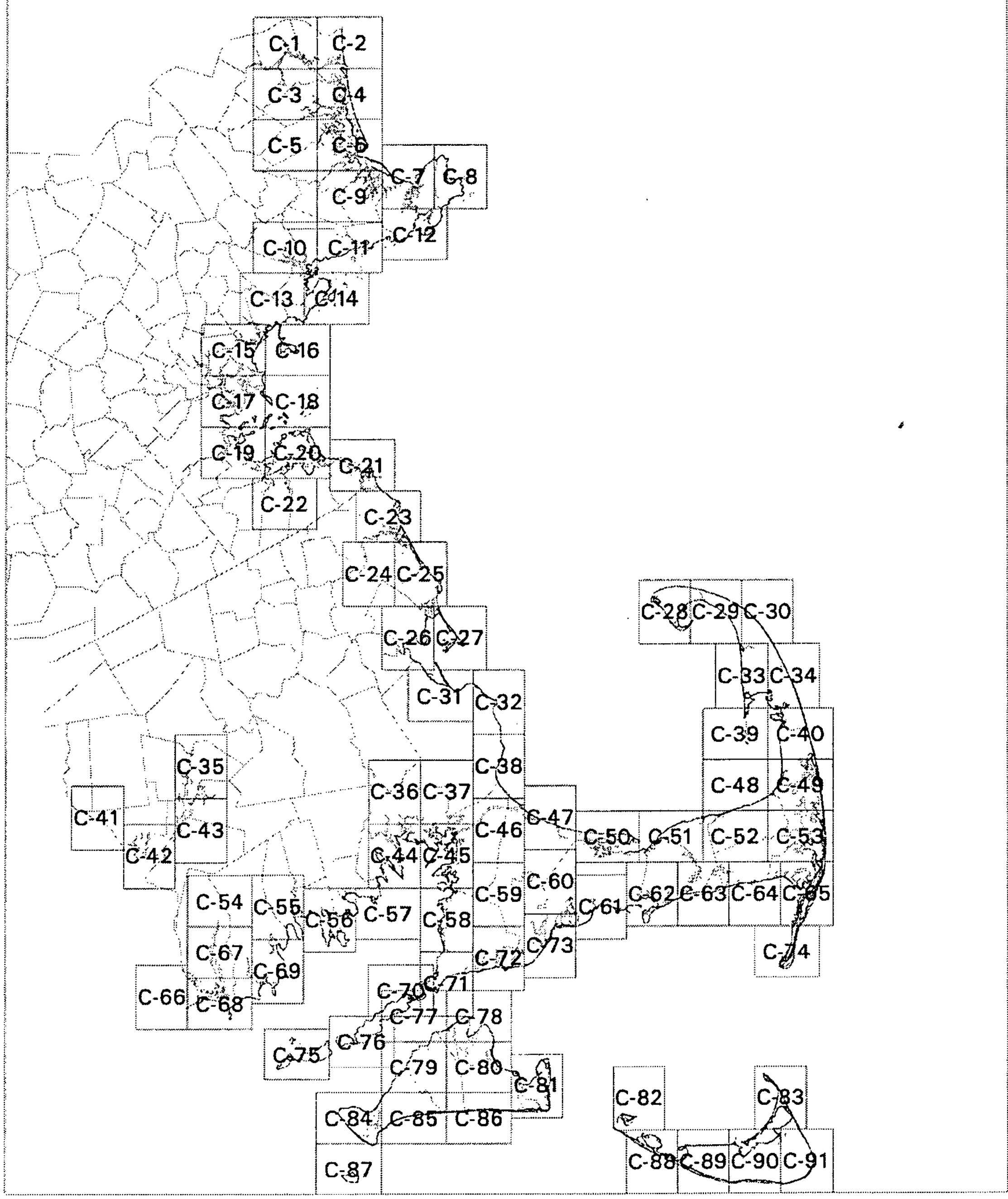
APPENDIX I
Index to Shoreline Change Maps

Massachusetts Historic Shoreline Change Index



Note: Shoreline Change Map Number is denoted by "C-#"

APPENDIX II
Removed Sections of Shoreline

Table 1: Sections of Shoreline Removed from Analysis Due to Inaccuracies

Map	Problem	Year	State Plane Coordinates	Solution (with identifying state plane coordinates)	Kilometers Removed
C-7	shoreline broken and offset 22 m to the southwest	1855	265834, 934207	Removed shoreline from 265818, 934203 to 263867, 934289	3.4
C-16	shoreline follows sand, not cliffs--shows 30 m erosion	1978	248609, 907471	Removed shoreline from 246332, 908331 to 248445, 908733	7.8
C-16	shoreline 73 m landward of promontory	1978	249208, 907869	Removed shoreline from 246332, 908331 to 248445, 908733	
C-20	peninsula has 70 m offset	1978	250424, 891892	Removed shoreline from 251335, 892196 to 252416, 891919	3.2
C-21	rock outcrop has 20 m offset	1938	260670, 888465	Removed rocky area 261005, 888025 to 260170, 888743	3.6
C-31	groin offset 8-23 m at Bert's Rest	1978	272647, 85517	Removed section of 1978 shoreline	5.4
C-31	Plymouth public beach groin offset 10-25 m	1978		Removed shoreline from 272455, 855352 to 276860, 855156	
C-32	14 m pier offset at nuclear power plant	1978	276341, 855643	Removed shoreline from 272455, 855352 to 276860, 855156	
C-33	22 m groin and pier offset Lieutenant Island	1971	321847, 854239	Removed shoreline from 322165, 852654 to 322460, 853491	3.2
C-44	mapped shoreline does not include marsh	1978	266042, 832322	Field checks to decide where high-water is in marsh	None
C-45	mapped shoreline goes behind marsh	1978	272733, 832701	Field checks to decide where high-water is in marsh	None
C-47	pier offset, 20 m groin offset, 44 m offset 1952	1978	308942, 867398	Removed shoreline from 285276, 835234 to 290488, 833203	5.4
C-48	groin offset	1978	260670, 888465	Removed shoreline from 316517, 836000 to 320539, 837396	4.4
C-48	mapped shoreline is landward of bluff	1978	265967, 832325	Removed shoreline from 316517, 836000 to 320539, 837396	
C-52	groin offset 100 m lateral, 36 m perpendicular	1978	315224, 835570	Removed shoreline from 314418, 835278 to 316517, 836000	2.3
C-80	inlet jetty offset 23 m	1978	95975, 46260	Removed shoreline from 495538, 48868 to 496871, 45394	4.2

APPENDIX III

Results of Differential Global Positioning System (DGPS) Field Checks of 1994 Orthophoto Control Points

The following table lists ground control points (GCPs) used to assess the horizontal accuracy of the 1994 orthophotos at selected points along the Massachusetts shoreline. The surveys were completed with the aid of Steve McKenna of CZM's Cape & Islands Regional Office, using a Trimble DGPS receiver. The receiver and post-processing steps yielded a horizontal accuracy of about 1 meter.

GCPs were chosen for their apparent stability through time (i.e., ease of finding in the field, probable lack of movement or redevelopment such as groin reconstruction or road relocation since 1994), as well as their proximity to the shoreline. Because the points are located adjacent to the shoreline rather than distributed throughout the orthophoto, they provide a measure of orthophoto accuracy near the feature of interest (the shoreline). These points were not surveyed with the intent of providing high-order geodetic control. Rather, they are intended simply as checks on the accuracy of the orthophotos near the shoreline.

Table 1 below lists the following items:

1) GCP identifier;
2) the latitude of the GCP measured on the orthophoto within ArcView;
3) the longitude of the GCP measured on the orthophoto within ArcView;
4) the latitude of the GCP measured in the field;
5) the longitude of the GCP measured in the field;
6) the forward azimuth (compass bearing) from the orthophoto-measured position to the field-measured position; and
7) the distance (offset) between the orthophoto-measured position and the field-measured position.

Table 2: Control Point Locations Used in Assessing Accuracy of 1994 Orthophotos

Map(ID)	Photo Latitude	Photo Longitude	DGPS Latitude	DGPS Longitude	Forward Azimuth	Dist. (m)
2	42°50'33.936"N	70°49'11.352"W	42°50'33.676"N	70°49'11.208"W	157°49'33.383"	8.7
2c	42°50'32.928"N	70°49'00.048"W	42°50'32.858"N	70°48'59.930"W	128°52'24.489"	3.4
4	42°47'44.736"N	70°48'42.588"W	42°47'44.741"N	70°48'42.590"W	-16°24'49.566"	0.2
8	42°37'31.512"N	70°37'28.812"W	42°37'31.561"N	70°37'28.815"W	-2°35'19.533"	1.5
11	42°34'29.352"N	70°46'22.080"W	42°34'29.356"N	70°46'22.301"W	-88°35'49.695"	5.0
14	42°29'45.492"N	70°51'09.252"W	42°29'45.607"N	70°51'09.244"W	2°56'49.161"	3.6
14b	42°29'46.824"N	70°51'09.216"W	42°29'46.653"N	70°51'09.210"W	178°30'45.393"	5.3
16	42°25'36.876"N	70°54'46.908"W	42°25'36.788"N	70°54'46.740"W	125°15'42.477"	4.7
28a	42°04'43.860"N	70°13'12.720"W	42°04'43.700"N	70°13'12.723"W	-179°11'59.005"	4.9
28b	42°02'12.552"N	70°11'47.868"W	42°02'12.590"N	70°11'48.060"W	-75°07'53.414"	4.6
28c	42°03'03.348"N	70°11'03.588"W	42°03'03.310"N	70°11'03.720"W	-111°07'09.304"	3.3
29a	42°02'09.276"N	70°05'49.416"W	42°02'09.230"N	70°05'49.266"W	112°21'37.825"	3.7
29b	42°00'19.620"N	70°04'46.668"W	42°00'19.689"N	70°04'46.698"W	-17°58'00.809"	2.2
30a	42°00'07.236"N	70°01'25.140"W	42°00'07.140"N	70°01'25.205"W	-153°12'17.816"	3.3
30b	42°02'02.184"N	70°03'59.040"W	42°02'01.889"N	70°03'58.925"W	163°47'41.735"	9.5
33a	41°59'26.268"N	70°04'14.088"W	41°59'26.367"N	70°04'14.189"W	-37°16'28.122"	3.8
33b	41°55'46.740"N	70°03'12.492"W	41°55'46.841"N	70°03'12.557"W	-25°40'04.102"	3.5
34a	41°56'38.688"N	69°59'06.864"W	41°56'38.609"N	69°59'07.001"W	-127°40'55.380"	4.0
34b	41°54'58.176"N	69°59'17.988"W	41°54'58.132"N	69°59'17.842"W	111°58'25.592"	3.6
46b	41°46'18.084"N	70°29'29.616"W	41°46'18.155"N	70°29'29.890"W	-70°54'25.059"	6.7
47b	41°43'52.608"N	70°24'21.312"W	41°43'52.667"N	70°24'21.503"W	-67°35'23.755"	4.8
48a	41°46'04.152"N	70°05'08.772"W	41°46'04.235"N	70°05'08.689"W	36°49'12.799"	3.2
48b	41°46'17.688"N	70°04'13.224"W	41°46'17.748"N	70°04'13.141"W	46°00'03.565"	2.7
49a	41°47'42.108"N	69°58'55.164"W	41°47'42.096"N	69°58'55.363"W	-94°36'25.288"	4.6
51a	41°45'08.496"N	70°11'18.780"W	41°45'08.527"N	70°11'18.747"W	38°33'35.054"	1.2
51b2	41°45'11.484"N	70°09'10.440"W	41°45'11.294"N	70°09'10.352"W	160°52'20.475"	6.2
61a	41°36'33.732"N	70°23'23.316"W	41°36'33.667"N	70°23'23.307"W	174°04'02.378"	2.0
61b	41°37'50.304"N	70°18'22.464"W	41°37'50.289"N	70°18'22.345"W	99°32'13.777"	2.8
62b	41°38'17.412"N	70°13'10.812"W	41°38'17.357"N	70°13'10.864"W	-144°39'13.673"	2.1
63a	41°38'40.956"N	70°12'07.560"W	41°38'40.874"N	70°12'07.543"W	171°09'39.252"	2.6
64a	41°39'36.576"N	70°06'19.404"W	41°39'36.520"N	70°06'19.410"W	-175°24'22.640"	1.7
71c	41°30'56.952"N	70°39'18.396"W	41°30'56.660"N	70°39'18.558"W	-157°21'52.500"	9.8
71e	41°32'33.144"N	70°36'07.704"W	41°32'33.064"N	70°36'07.898"W	-118°45'42.057"	5.1

Field Description of Ground Control Point Locations

The following table lists the control points surveyed for this project. These brief descriptions are intended for use with the ArcView shape file coverage provided on the data CD that accompanies this report. The coverage shows these points with the descriptions below as attributes. When viewed with the orthophotos as an underlay in ArcView, the points can be easily identified for use in the office or recovery in the field.

Table 3: Field Description of Ground Control Point (GCP) Locations Used in Assessing Accuracy of 1994 Orthophotos

Point	Field Location
2	road-beach corner of landward wing of hotel
2c	tip of median
4	NW corner of intersection
8	SW corner of building
11	SE corner of concrete pier
(12)	NE corner of tennis court (excluded due to excessive interference with reading)
(14)	SE corner of concrete pier (excluded due to excessive interference with reading)
14b	SE corner of deck
16	E corner of tennis courts
28a	SE corner of building N of E side of airport
28b	E side of base of jetty
28c	E corner of concrete pier
29a	inner corner of intersection
29b	inner corner of loop (at South side of loop)
30a	SW corner of intersection
30b	N edge of asphalt where dirt road intersects
33a	NE corner
33b	NE corner of N court of red/green courts (S of 2 sets of courts)
34a	NW corner of building
34b	S corner of building
49a	W corner of building
46b	center of loop in road
47b	NW inner corner of loop in road
48a	SW corner of intersection
48b	inner SW corner of triangle
51a	corner of groin
51b	SW corner of building by inlet
51b2	corner of seawall
61a	SW corner of intersection
61b	SW corner of intersection
62b	NE corner of E wing (wing runs N-S)
63a	NW corner of building
(63b)	SW corner of building by inlet (excluded due to difficulty in locating the chosen point)
64a	NE corner of W wing of building
64b	Inner S corner of triangle
71c	SW corner of Nobska Lighthouse
71e	W corner of intersection in Falmouth Heights

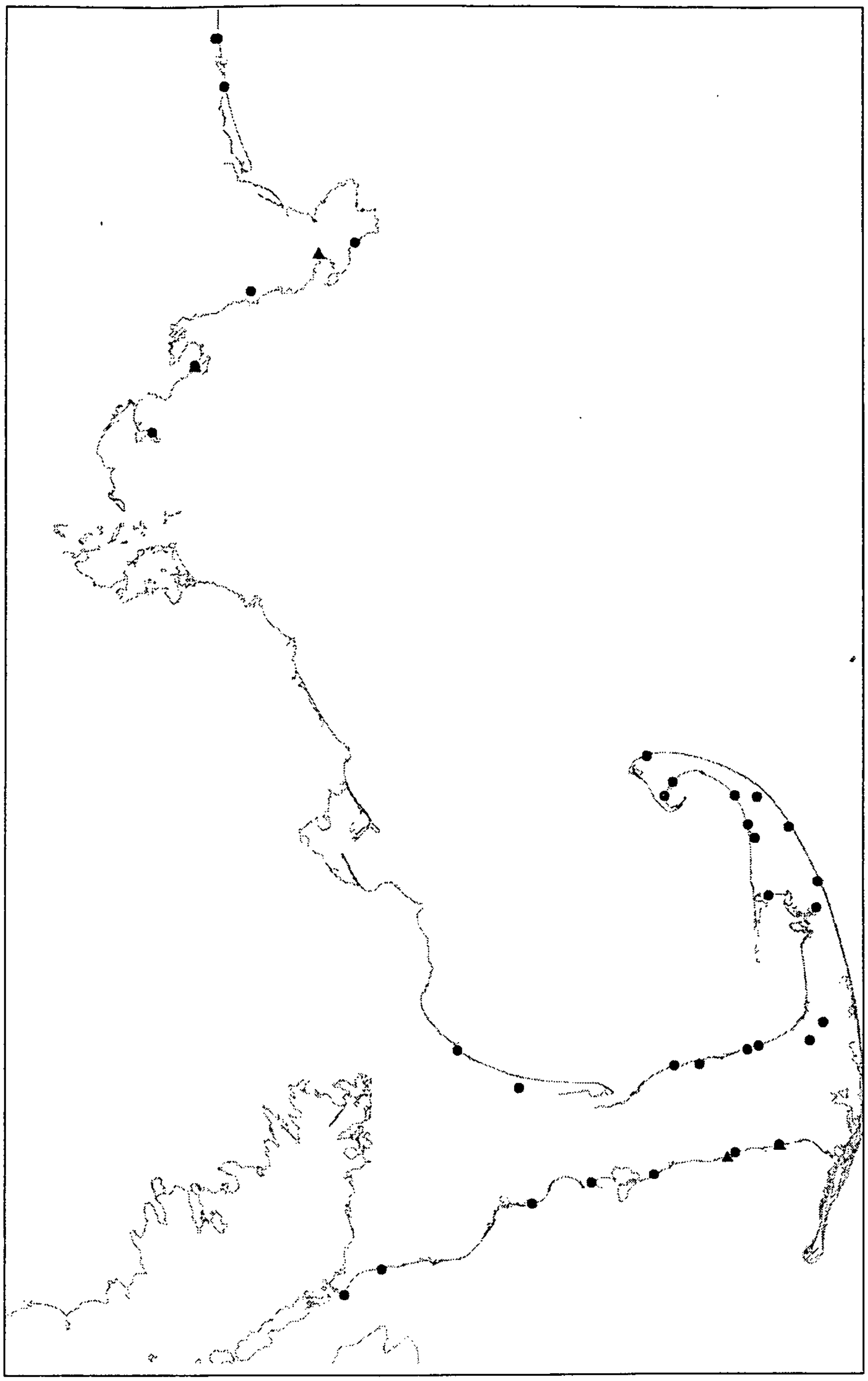


Figure 6: Map of Ground Control Points Used to Assess the Accuracy of the 1994 Orthophotos. (Circles indicate points used in the accuracy assessment. Triangles indicate points not used due to inability to recover the points in the field (e.g., roads moved or widened, groin reconstructed, etc. since 1994.)

APPENDIX IV

Reprint of Applied Geographics Inc. Methodology for Previous Shoreline Rate-of-Change Study

Charles Van Dusen

Vector Based Shoreline Change Analysis

Abstract

In a cooperative effort funded by the National Oceanic and Atmospheric Administration (NOAA) specifically the Office of Coastal Resource Management (OCRM) and managed by Massachusetts Coastal Zone Management (MCZM), Applied Geographics, Inc. (AGI) performed a vector based historic shoreline change analysis using Arc/Info vector coverages, AML, and C. Linear historic shoreline data as early as 1844 and as recent as 1982 were provided and an analysis was undertaken to define and execute a procedure for deriving the historic rate of shoreline change using a vector-based methodology. Programs written in C were modified to handle the complexities of the Massachusetts historic shoreline data. The data were segmented for analysis and then appended to a single State-wide dataset comprising nearly 30,000 sampling points. Custom plots were created and delivered for distribution and a MS Access database interface was designed and delivered to permit interactive statistical query of any single sampling point or any contiguous series of sampling points.

INTRODUCTION

Coastal zone managers, emergency management officials, and coastal property owners need to be aware of the potential risks to coastal property before, during, and after severe storms and hurricanes. As new sensors become available and new technologies are focused on the problems of hazard mitigation in the coastal zone, a wealth of data is being generated which will permit volumetric analyses of recent landform morphology along the coast (SAR, LIDAR). These data may be able to provide high spatial and temporal resolution surficial forms for modeling recent changes, yet to understand the longer-term fluctuations for which these data are not available, historic linear data may be exploited. Currently, historic linear data provides us with the ability to assess future changes in the shape of the shoreline by reviewing historic snapshots of the shoreline. The long-term rates of change provide managers and property owners with a clearer picture of the potential hazards confronting coastal development.

The Massachusetts coast is highly variable, characterized by rocky headlands framing sandy beaches and salt marsh. Defined in linear terms, the shorelines are convoluted, circuitous shapes. Their complexity is further complicated by time series replication showing the temporal, morphological changes in the shoreline. New methods for developing hi-resolution surficial data may supplant the need for performing these types of linear temporal shape analyses, yet historic data still provides a substantial resource archive for evaluating future coastal hazard risks from historic trends.

METHODS

Study Area

The study area for shoreline change analysis includes the entire Massachusetts shoreline spanning approximately 1500 statute miles. Analysis was completed in all areas where the data was deemed by state coastal geologists to be sufficient for realistically estimating long-term shoreline change rates.

Data Utilized

MCZM provided AGI with a historic shoreline dataset with a temporal span of nearly 140 years for the Massachusetts shoreline. This dataset was automated from a number of sources, including NOAA/NOS topographic map sheets, FIS (FEMA) topographic map sheets, hydrographic map sheets, USGS quadrangles, aerial photos, and orthophotos. The source data were evaluated for error and accuracy prior to conversion and then plotted for delivery to MCZM at a scale of 1:5000. These plots were subsequently digitized to create the Massachusetts historic shoreline dataset. This dataset, in Arc/Info coverage format including attributes describing the date of each shoreline, was delivered to AGI for analysis.

The shoreline data are both temporally inconsistent and spatially inconsistent. No shoreline for any year spans the entire coast, nor does any year/shoreline necessarily have a consistently earlier or later year/shoreline. Rather, the data are spatially and temporally dispersed. Further, the data as delivered had a temporal resolution of 1 year. The shorelines were thus assumed to provide the shape of the high-water line at a single date during the calendar year and were assumed to be reliable for use at 1:5000 scale. The table below outlines the temporal distribution of the shorelines and their summarized lengths across the entire Massachusetts shoreline.

Temporal Distribution of Historic Shorelines and their Extent in Linear Miles

Year	Miles	Year	Miles	Year	Miles	Year	Miles	Year	Miles	Year	Miles
1844	28.03	1853	47.19	1886	64.57	1896	8.09	1938	250.46	1970	35.86
1845	170.64	1854	8.12	1887	93.20	1897	61.73	1948	69.77	1971	19.67
1846	120.95	1855	9.75	1888	29.88	1909	12.29	1950	16.02	1972	35.71
1847	67.82	1856	8.51	1889	40.52	1912	5.10	1951	185.58	1975	40.05
1848	58.00	1858	10.97	1890	33.43	1919	43.22	1952	128.05	1978	534.21
1849	45.06	1860	11.25	1892	30.08	1924	2.15	1954	20.33	1979	35.82
1850	5.45	1866	8.71	1893	33.15	1928	26.21	1955	178.56	1982	8.40
1851	31.09	1867	6.51	1894	10.69	1933	78.83	1962	28.93		
1852	4.52	1868	73.54	1895	169.27	1934	69.99	1969	6.16		

Analysis

The historic shoreline data were segmented for analysis. The criteria used to segment the data were developed within the analysis methods to provide consistent, accurate, and timely temporal shoreline change analysis results. The data were divided into approximately 100 analysis segments considering (in part) the following criteria:

- A minimum of 2 shorelines (required to develop a rate of change).

- Manageable size <= 5 Megabytes of baseline and shoreline Arc/Info coverage data.
- Segregate opposing shoreline data to reduce possiblity of year/shoreline contention.
- Aggregate shorelines of consistent spatial variability to allow consistent transect *extend* distances.
- Where possible, group, maintain, and analyze distinct geographic features.

Once the historic data were segmented into these manageable units, transecting and analysis proceeded within each of the analysis units. Baselines were constructed on the upland side of all historic shorelines to provide a starting point for the transecting operation. Baselines were digitized parallel to the general trend of the historic shorelines so that orthogonally oriented transects originating from the baseline would most closely match transects placed by manual 'best fit' methods. These baselines coverages were SPLINEd, GENERALIZEd, and DENSIFied to provide a good origin point for each of the transects cast.

With baselines and historic shoreline data coverages present for each analysis segment, a suite of C functions were called to generate transects, perform the analysis and deliver results in Arc/Info GENERATE format. The original C code was developed for the USGS and is described in Open File Report Number 92-355 (Danforth and Thêiler, 1992) as the Digital Shoreline Analysis System (DSAS). The C code was redesigned by AGI to perform accurate, high-resolution temporal shoreline change analysis on shorelines which are complex in shape and in orientation. These modifications included code to perform the following tasks:

- Distinguish direction to uplands from direction to shoreline and cast sampling transects only in the direction of the historic shorelines
- More frequent, more accurate transect sampling
    - Cast sampling transect at every line vertex.
    - Bisect the orthogonals of adjacent baseline segments to derive bearing of sampling transect.
- Project position of 'potential' future shorelines from long-term historic shoreline change rate.

Whether long stretches of sandy beaches, migrating inlets, or salt marshes, these functions are capable of casting an orthogonal sampling transect, measure the distances, and compute the interim and overall rates of movement along the sampling transect. Additonal statistical functions provide estimations of the long-term shoreline change rate and the 30 year and 60 year projected positions of the shoreline along the sampling transect. Geographic data was output in GENERATE format and attribute data were output in a format suitable for input into INFO or any commercial database. Unique identification codes provided the link between geographic and attribute data which were subsequently joined using JOINITEM.

Data Output

Within each analysis segment, the output transect coverages were GENERATEd, attributed, and APPENDed to a single statewide line coverage. This line coverage consists of nearly 30,000 transects with attributes describing the interval rates of change, overall long-term rates of change, miscellaneous statistical measures, and the 30 year and 60 year projected coordinate positions of the shoreline.

Map and Data Products

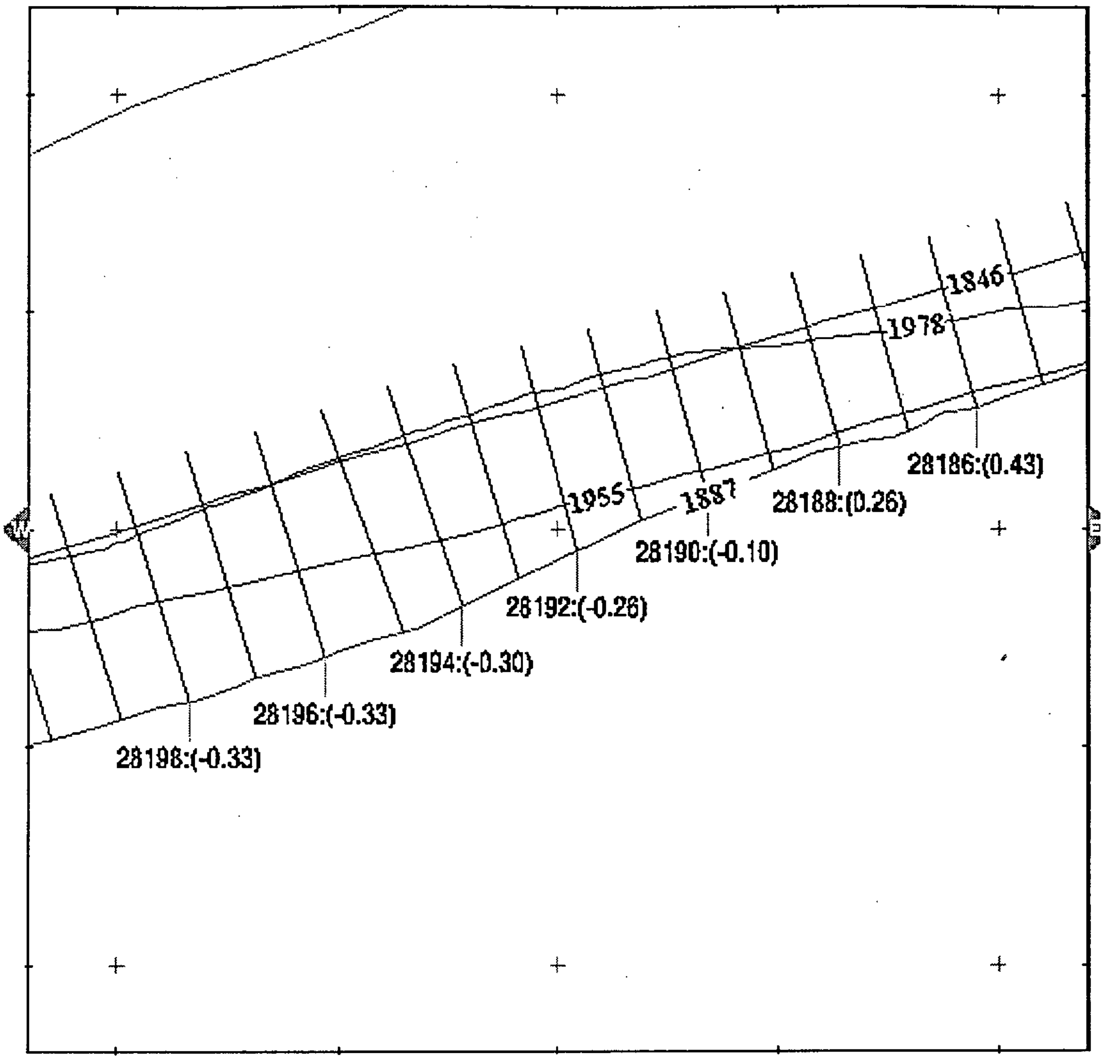
A map index for the Massachusetts coastal zone was built and plots conforming to the index were created and plotted at 1:10000 scale on paper and on mylar for overlay with orthophotography. These plots are being distributed to coastal zone managers, town planners, and the public to support coastal hazard assessment, coastal economic impact analysis, and property assessment applications. In addition to plots, an MS ACCESS database and query interface was designed and delivered to allow MCZM geologists to analyze the shoreline change results for any individual transect or series of transects.

Web Display

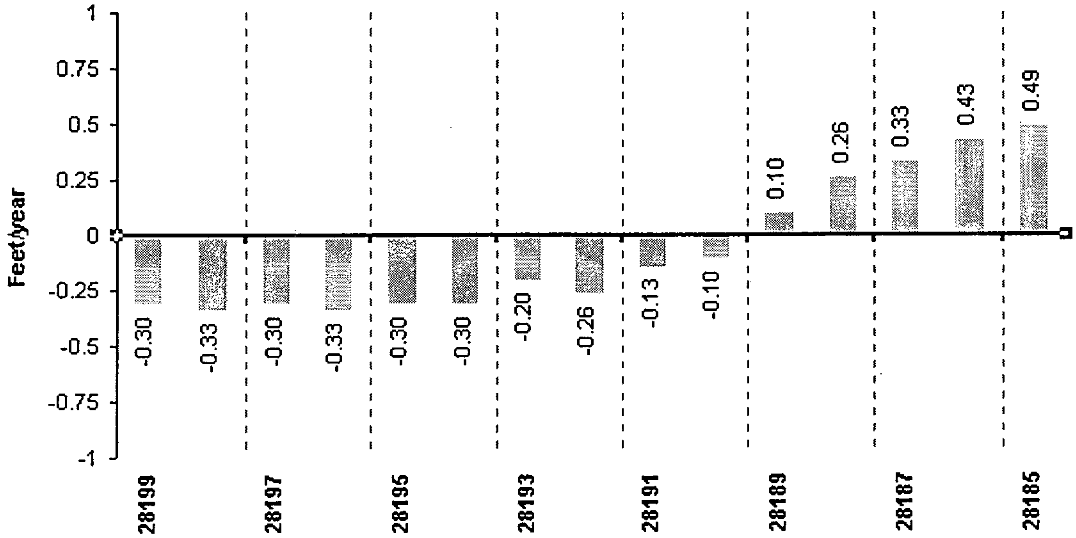
Shoreline change data plots were converted to GIF format and embedded within an HTML application for ease of browsing and display. This application is available for browsing for a limited time at www.appgeo.com beginning in May, 1997

A limited section of the shoreline change data and analysis results are presented below. Note the shift from net overall loss (erosion) to net overall gain (accretion) as the analysis moves from left to right. Uplands are at the top of the image, offshore areas at the bottom of the image. Transects are spaced at 50 meter intervals. Scale is 1:4500.

Historic Shoreline Change Analysis



1846
1978
1955
1887
28186:(0.43)
28188:(0.26)
28190:(-0.10)
28192:(-0.26)
28194:(-0.30)
28196:(-0.33)
28198:(-0.33)



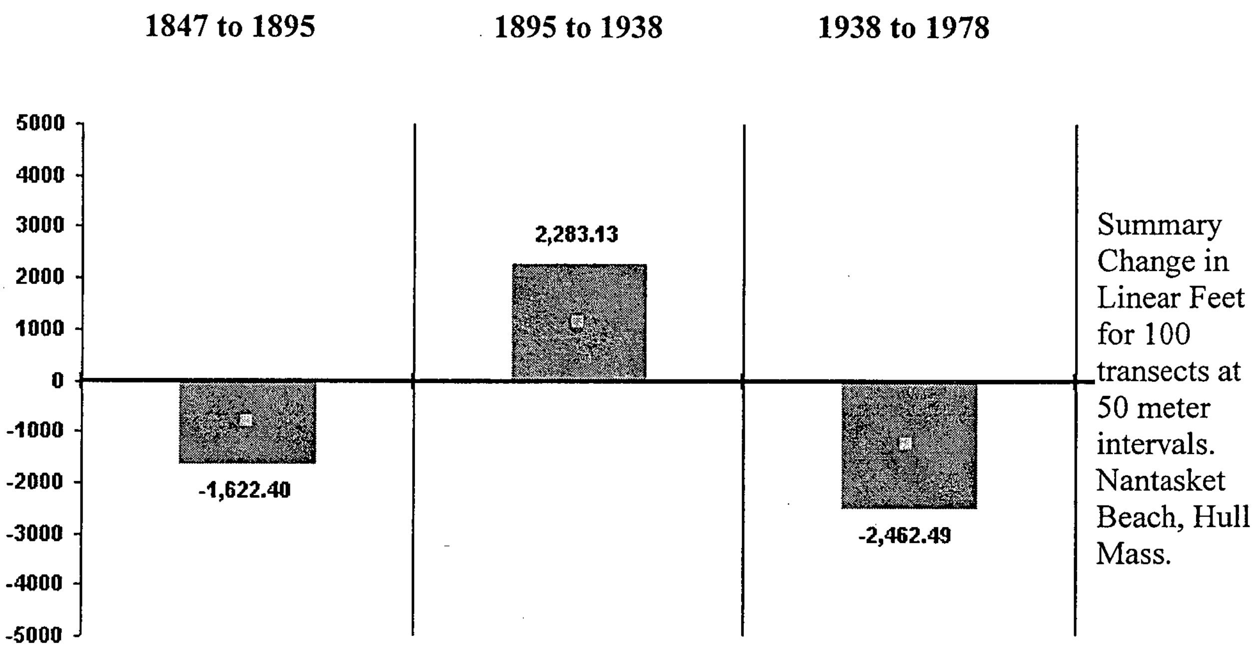
Feet/year
1
0.75
0.5
0.25
0
-0.25
-0.5
-0.75
-1
-0.30
-0.33
-0.30
-0.33
-0.30
-0.30
-0.20
-0.26
-0.13
-0.10
0.10
0.26
0.33
0.43
0.49
28199
28197
28195
28193
28191
28189
28187
28185

RESULTS

As the above images illustrate, some areas of the Massachusetts coast are eroding and some are accreting. For the entire Massachusetts shoreline, sampling transects which indicate erosion outnumber those which indicate accretion roughly 2 to 1. Additional temporal summary statistics are provided only for areas where temporal and spatial consistency of the data allows them to be generated. A multitude of additional statistics are available for transect analysis within the ACCESS interface, including interim temporal rates of change with their **Variance** and **Standard Deviation** for all interim rates, **End-Point Rate, Average of Rates,** and **Linear Regression Rate** (used as long-term rate for this project).

The figure below presents a summary of the temporal change for a stretch of coastline spanning 100 transects (approximately 5 kilometers) of Nantasket Beach in the town of Hull. Each bar in the chart represents the overall summarized linear change in the shoreline for the time period. In this sample area, summary temporal statistics suggest a trend in the data showing overall erosion for the selected area from 1847 to 1895, accretion from 1895 to 1938, and erosion from 1938 to 1978.

Total Linear Change for Portions of Nantasket Beach (Hull, Massachusetts)



Vector based shoreline change analysis provides a model of temporal erosion and accretion for any set of linear historic shoreline data. The vector approach to analyzing historic shoreline change data contrasts with a raster approach in its sampling flexibility and temporal scaleability. The vector approach developed above can accept any number of temporal linear representations of the shoreline and can flexibly sample those shorelines to calculate past variability and project future changes.

CONCLUSION

Historic rates of shoreline change provide valuable data on erosion trands and permit limited forecasting of shoreline movement. Automated GIS shoreline change analysis provides rapid, high-resolution evaluation of multiple temporal shoreline delimitations. There is room for improvement on the methodology described above, which will be implemented in future analyses as new shoreline data becomes available. Arc/Info embeds the functionality of the C programs used here in COGO. Nonetheless, this methodology demonstrates that the plotting strengths of Arc/Info can be combined with C functionality using standard ASCII files for data transfer and communication.

Other applications include linear shape change analysis for any spatial phenomenon which can be defined and delimited for at least 2 time periods. Spatial migration of distinct geographic features is a documented phenomenon whose morphology is of substantial interest to resource managers and geographers.

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